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SOIL BULK DENSITY AND PHYTOSANITARY CONDITIONS AT POTATO FIELD

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ABSTRACT. The aim of this paper is to present the microorganisms and their activities and soil bulk density. It is a fact that both have a great impact on soil fertility and its health status. Among the microorganisms in soil, the bacteria and fungi are the most important ones for potato cultivation; the bacteria living on the plant roots serve to uphold the nutrient intake of plants. Our previous research has shown that *Paenibacillus Polymyxa Rizobacter* fostered a better uptake of phosphorus and reduced drought stress. The potato experiments were conducted in a pH range of 5.4 to 5.9, so it was environmentally favourable for the development of soil fungi. It is well known that moulds have a well-developed filiform and a high spore production. We have found that if the genus *Alternaria*, *Helminthosporium*, *Fusarium*, *etc*., has been left on the surface of the skin of potatoes then it will affect the disease. In 2010, the mould count remained within the range from $0.83 \cdot 10^5$ to $2.25 \cdot 10^5$. Also according to our assessments, an economic loss related to unfavourable soil bulk density for potato will occur if it is more than 1.25 ± 0.07 Mg m^{-3}. At the same time, it should be noted that for the Estonian soil conditions, the accepted limit of penetration resistance is 1.0 MPa.

Introduction

Problems concerning soil phytosanitary conditions in Estonia were connected with lack of attention. We have found only one very interesting and deep investigation into the matter (Truu, 2008). At the same time, the soil bulk density has been investigated separately in great detail. In terms of the phytosanitary aspects, it is only the research by Marika Truu that has been carried out in a detailed manner. The author mentioned above has noted that soil microorganisms have a fundamental role in such complex systems by stabilizing soil particles, performing organic matter decomposition, and mediating nutrient cycling and energy; at that, Marika Truu (2008) has referred to Doran and Zeiss (2000). It is hard to disagree because microorganisms are playing a very important role not only in stabilizing soil particles but also in improving soil bulk density. Due to the fact that microorganisms are considered as sensible indicators (Bending *et al*., 2004; Bossio *et al*., 2005; Ratcliff *et al*., 2006; Stark *et al*., 2007; Deurer *et al*., 2008), the soil bulk density plays not only the role as sensitive indicator of soil physical properties, but, at the same time, it provides an easily understandable characteristic trait not only for agronomists, biologists, *etc*. but also for agricultural mechanics and engineers.

Relying on the aspects provided above, the objective of our investigations included: 1) to identify the soil physical properties and phytosanitary status of a potato field; 2) to find suitable ways for increasing the microbial activities and the total number of bacteria; 3) to explain the persistence of the pathogens in soil.

Materials and methods

The field experiments were carried out in 2007 (was as exploring), 2008, 2009, and 2010, and the subsequent tests with potato in 2008, 2009, 2010 and 2011. The potato field experiments have been established on the experimental field "Kõbuaed", at Saku, Harju County (preparing the potato field by traditional technology), as well as the industrial field No 4 of Mr. Kalle Hamburg farm at Ingliste, Rapla County (preparing the potato field by Scottish technology. This field was for us as pattern).

The plot size of the field "Kõbuaed" was 21 m^2 (total 63 m^2), and the field No 4 at Ingliste –3.4 ha, respectively. The number of repetitions was a three and the scheme of experiments was in series. The test varieties of potato was a very early variety "Elfe".

Fertilizer of potato at the field "Kõbuaed" was Cropcare 10-4-17 NPK 1000 kg ha^{-1}. Agronomic performance test area: pH 5.4–5.9; P 125–147 mg kg^{-1}; K 165–195 mg kg^{-1}; Ca 1890–2420 mg kg^{-1}; Mg 59–96 mg kg^{-1}; humus 2.7 %. The field experiments have been founded on luvi-humic gleysol (WRB) with loamy sand texture. Production experiments were carried out on Mr Kalle Hamburg's farm at Ingliste on the calcareous loamy sand soil.

The overall physical conditions of the soil of the "Kõbuaed" were determined. For observation of soil water content was used the TDR (Eijkelkamp equipment), for penetration or cone resistance –hydraulic penetrometer "Alex", and for bulk density – Litvinov's ring kits. For measuring the profile of potato's furrow (Figure 1) we have used the special profilometer (designed by E. Nugis).

Figure 1. Profilometer for measuring the profile of potato's furrow (this picture represents the situation at the field at Ingliste, in which the Scottish technology has been used).

For assessing the phytosanitary status we have taken the soil samples at "Kõbuaed" in the harvest period, *i.e.* every year of the trial period. These samples were analyzed in the laboratory of plant health and microbiology of the Agricultural Research Centre by means of the following ISO standard methods: ISO 10390-94; EVS-EN 13040:2000; ICC nr 125 and 144; ICC nr 146 and TTML MB4. The soil phytosanitary status and pathogens are estimated by the moist chamber method with growing out the adherend and also cultivating at different adherents; also the Elisa test has been used. The total number of bacteria, count of mesophile of spore bacteria, mould and also the presence of Fusarium were determined. The determination of the weeds was based on the guide of EPPO (European PlantProtection Organisation) and requirements concerning a Good Experimental Practice (GEP). The fractional state of the potato tubers was set by the quadrangular fractionator. The tuber weight was measured and taken for the basis for the related estimations. The fractional state ranged between <28 mm and >70 mm.

The weather conditions during field experiments were typical for North part of Estonia (precipitations during vegetation period of potato in an average per month about 120 mm). The weather conditions for potato growth during trial periods are more favourable in the 2009 year than in 2008 and 2010 was more rainy years. In the year 2011 were the weather conditions analogous to the 2010 year.

The statistical estimation of data of the field experiments has been carrying out by t_{05}-criterion of Student.

Results

The soil bulk density in the different part of potato furrow changes greatly. More favourable level of bulk density is located in the centre of potato's furrow (Figure 2) and extends to a depth of 18–20 cm, whereas the flank and bottom of potato's furrow have different conditions.

The flank of the furrow is slightly more compacted, but since the soil of the "Kõbuaed" field is a relatively light one, then also its soil bulk density remains accordingly 1.06–1.25 Mg m^{-3}. For the bottom of the furrow, the bulk density was significantly higher, resembling a pouch (Figure 2). The same pouch can be seen in the graph curves of the penetration or cone resistance (Figure 3).

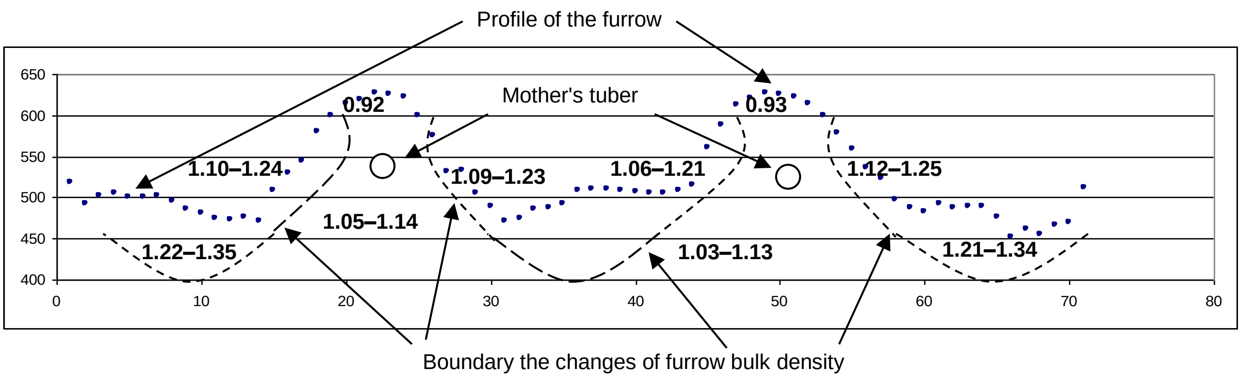

Figure 2. Soil bulk density in the experimental field "Kõbuaed" (average level Mg m^{-3}) of the bottom, flank and ridge in the potato furrow (maximum LSD_{05} = 0.07 Mg m^{-3}).

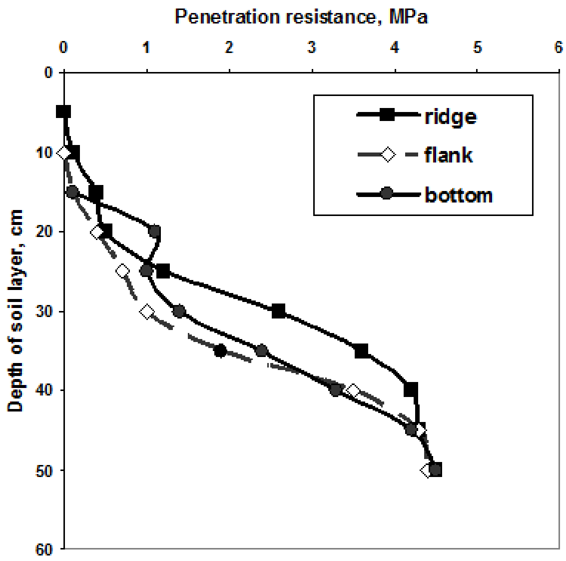

Figure 3. Soil penetration resistance in the experimental field "Kõbuaed" related different part of potato furrows (n = 11, maximum LSD05 = 0.31 MPa; soil volume water content (%vol) v/v = 17.6 ± 0.9)

In results of our investigations, we have found that the penetration resistance (Figure 3) varied in the depth of potato's seed tuber within 0.0–0.6 MPa (LSD_{05} = 0.06 MPa). In other words, LSD_{05} is significant at the probability level 0.06.

Penetration resistance proved to be higher in the bottom of furrows and remained in the range of 0.2–1.2 MPa (LSD_{05} = 0.21 MPa). For potato growing the permissible limit of cone resistance is 0.1 MPa, and the relevant bulk density –1.15 Mg m^{-3}.

With regard to the soil volume water content, this depends greatly on the years and the least of the potato growing technology. The soil volume water content for potato growing was more favourable in 2009 when the soil water content remained within 14.6–26.6 %vol (LSD_{05}=2.2 %vol). Hereby, our opinion is that the influence of weather conditions on soil physical properties was direct.

Interestingly enough, usually the total number of bacteria in the soil is depending on the agrotechnical aspects (Figure 4).

According to Figure 4, we have a most higher level of bacteria, fusarium and mould related spring barley 'Anni' trial, but inversely for the trial of spring rape 'Adios', we have had most lower results. The conditions for the development of soil bacteria is advantageous if the soil pH = 6.0 or more because that is exactly what is needed for neutral or alkaline growing conditions. The pH of the experimental field was lower, and, therefore, it was noticeable, but during the potato growing, there was a certain alignment of soil bacteria.

At the same time, it's very interesting to note that the mould count (Tartlan *et al.*, 2011) remained at the 2010th in the range of $0.83*10^5$ to $2.25*10^5$. Potatoes suffer from a large number of diseases, which can seriously reduce their yield especially in wet or unfavourable years, when the tubers may get infected (Table 1).

Table 1. Results of tubers skin infection with soil-inhabiting pathogens (for potato nest average = 1557 g; maximum LSD_{05} = 363 g)

No. of soil sample	The infection of soil-pathogens	Yield of potato nest, g
1	*Rhizoctonia solani* *Helminthosporium solani* *Streptomyces scabies*	847
2	*Rhizoctonia solani* *Streptomyces scabies*	1450
3	*Rhizoctonia solani* *Streptomyces scabies*	2000
4	*Rhizoctonia solani*	1800
5	*Fusarium* spp. *Streptomyces scabies* *Helminthosporium solani*	1600
6	*Fusarium* spp. *Alternaria solani*	1870
7	*Rhizoctonia solani* *Streptomyces scabies*	1330

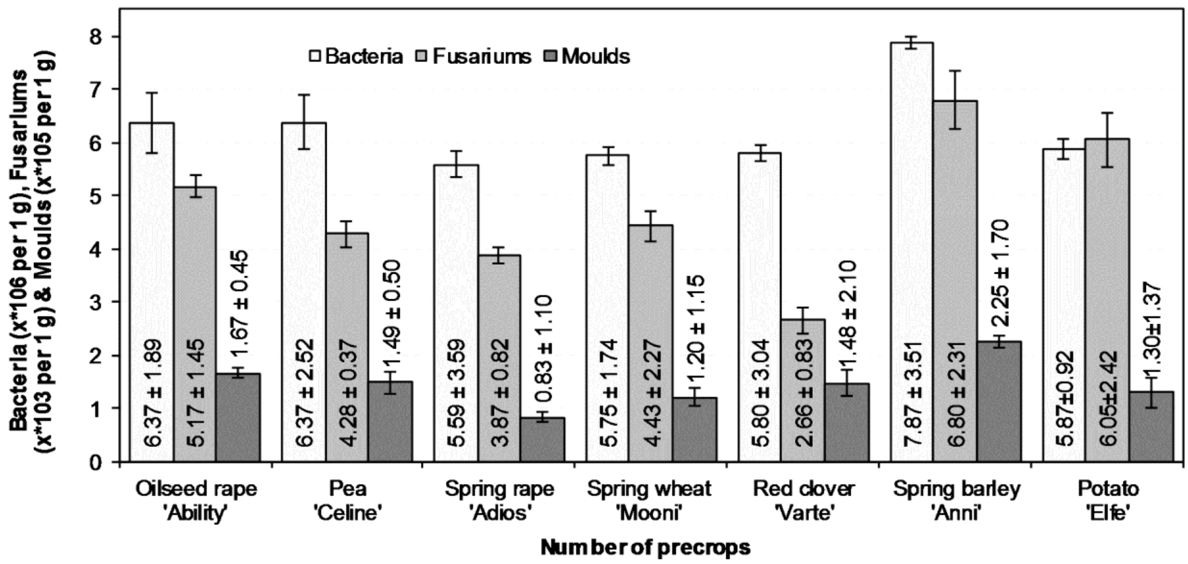

Figure 4. Bacteria, Fusariums and Moulds content (± LSD_{05}) in different soil samples of preceding crops at the field "Kõbuaed" in Saku (sequence the trial plots of precrops at "Kõbuaed" field the same with a number of precrops)

Discussion

According to the information in the literature (Nugis *et al*., 2014), for us it is is very important to note that the main characteristics for the soil physical properties are soil bulk density (Kadaja *et al*., 2009; Nugis *et al*., 2009). Also, it is possible to measure the soil cone resistance by penetrologger, whereby the bulk density could be characterized. We have identified that it is possible to measure the soil penetration resistance only when soil water contents within 0.7–0.9FC (FC – Field Capacity) or 11.0 (%g g^{-1})–14.0(%g g^{-1}). However, these data we have had only for luvi-humic gleysol with loamy sand texture in the field "Kõbuaed".

It is an important fact that (Nugis *et al*., 2014) there has been much discussion among the scientists on the topic as to how it would be possible to characterize the soil physical properties by penetrologger, because the soil cone resistance will depend generally on the soil moisture content. It is an incontrovertible fact that if the soil humidity is equal to the level of soil physical maturity, it will be possible to determine the soil bulk density by means of measuring the soil cone resistance. When cone resistance is being measured by the penetrometer, an average or high level of soil compaction could be assessed. "Many authors (Cubrinovski *et al*., 2001; Botta *et al*., 2010; Reintam *et al*., 2009; Kuht *et al*., 2012) indicated this opportunity" (Nugis *et al*., 2014).

At the same time, we have found that in the case of bulk density, we have two alternatives for describing the soil bulk density through penetration or cone resistance; these include: exponential relationship $\gamma = 0.95e^{0.07k}$ and linear relationship $\gamma = 0.09k + 0.92$, where k–penetration or cone resistance (MPa) and γ-soil bulk density (Mg m^{-3}). However, it should be noted that the equation of linear relationship is describing better the top soil layers and equation of exponential relationship – for subsoil layers.

In order to obtain new knowledge for higher quality potato growing for improving the quality and nutritional value of potatoes, the complex investigations have been carried out.

Concerning the soil phytosanitary conditions (Tartlan *et al*., 2011) during the potato growing period, our complex research has shown that *Paenibacillus Polymyxa Rizobacter* fostered a better uptake of phosphorus and reduced drought stress.

General *Alternaria, Helminthosporium* and *Fusarium etc*. (Tartlan *et al*., 2011) are the main moulds that affect the below-ground portions of potato plants. For us, it was also a very important fact that the tuber surfaces were infested by *Rhizoctonia solani, Helminthosporium, Fusarium, Streptomyces scabies, etc*. Infestation of tubers showed that phytosanitary status of soil requires some improvement. In terms of food safety, it is crucial to reduce the surface contamination by pathogens.

The most important mould genus, affecting the potato disease resistance (Tartlan *et al*., 2011), include *Alternaria, Helminthosporium, Fusarium*, etc.

The potato experiments were conducted in a pH range of 5.4 to 5.9. It was a favourable environment for the development of soil fungi. Moulds at shallow layer need 20–21% of soil water content for the development moulds filiform and with high spore production.

To establish the necessary phytosanitary conditions for available potato growing (Table 1), the vernalization of seed potato is also important. This has also been pointed out by Stevenson *et al.* (2001), as he notes: "to minimize disease losses, the amount of soilborne and tuber-borne inoculum must be reduced. Crop rotation will reduce soilborne populations of R solani Ag-3". We have used also crop rotation, but the results are yet to be analysed.

The vernalization technology of seed potato has been widely used by the potato producers. In order to improve the cost-effectiveness, the vernalization technology has been improved by Kalle Hamburg, who transferred the vernalisation of seed potato into the closed meshed bags.

It should be noted that the vernalization will increase the fractional uniformity of yield, the optimum soil humidity, nutrients and disease resistance. To results of the research aimed at improving the external quality of potato tubers and reducing infection (Table 1, sample No 4) have been taken into practical use. It is also important to know that on neutral or alkaline soils, physiologically acidic fertilizers or sulphur are used to temporarily modify the soil nutrient solution.

Some authors (Lambert, Loria, 1989; Miyajima *et al*., 1998) have written that "the fungus forms spores that persist in the soil and can survive there for several years, still being infective. After the attached soil may become contaminated with spores of this fungus and it can lead to an infection during storage". And it is said that "After storage of seed potatoes this fungus can be transferred to soil because spores are attached to the skin of the tubers". "Common scab incited by *Streptomyces scabies* is widely distributed across the world and causes marketable losses in potato production due to worse quality. Soil reaction and moisture are the most important factors affecting scab infection" (Lambert, Loria, 1989).

Concerning *Fusarium* author Stevenson *et al.* (2001) wrote a right (pp. 23–25) "the dry rot disease is caused by the fungus *Fusarium* infecting mainly stored tubers and seed tubers after planting. Soilborne inoculum is present on the surface of harvested tubers and contaminated equipment, infection occurs through wounds caused by mechanized harvesting and handling".

Finally, we suggest that the following aspects require some further investigations:

1. to specify the growth of modern diseases and food safety;
2. to specify infections with pathogens through the peel of potato;
3. to improve the preservation of potato for food and to examine the changes in its quality during the storing period;

4. to carry out a preservation trial to determine the vitamin C content in potato tubers;
5. to study the complex effects of new fertilizers and specification of the quality of potatoes during the growing season;
6. to provide the producers, by means of an online system, with the necessary information regarding the research results, including introduction, materials, methods, new approaches, and recommenddations for an effective production.

Conclusions

The results of our investigations have shown that the method for determining (the first time in Saku) the soil bulk density and penetration resistance has helped to identify the potato growing conditions.

It is more appropriate to grow the potato tubers in the Estonian conditions of loamy sand luvi-humic gleysol if the penetration resistance <0.1 MPa and soil bulk density will not exceed 1.15 Mg m^{-3}. Actually, the soil bulk density was 0.92–1.13 Mg m^{-3}.

By selecting the precrops correctly, it will be possible to reduce the infection of potato yield with soil-inhabiting pathogens and to ensure a better health of the potato plants.

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All of the above will depend on an effective co-operation. We have had a fruitful cooperation with the PA Talukartul and Eesti Kartul NPA, as well as small-scale producers from Võru and Harju County. In the field of plant protection and fertilisation, we have been cooperating closely with Baltic Agro Ltd.

Conflict of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Author contributions

Study conception and design LT – 80%, EN – 20%.
Acquisition of data LT – 80%, EN – 20%.
Analysis and interpretation of data LT – 60%, EN – 40%.
Drafting of the manuscript LT – 57%, EN – 43%.
Critical revision and approved the final manuscript LT – 50%, EN – 50%.

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